Coastal Engineering Technical Note

ESTIMATION OF ECONOMIC LOSSES AS A FUNCTION OF WAVE HEIGHT COMPUTER PROGRAM: BWLOSS1 (MACE -15)

PROGRAM PURPOSE: The microcomputer program BWLOSS1 is intended to aid planners of coastal structures which provide protection from wave attack by deriving an empirical mathematical expression relating economic losses from wave effects to the responsible significant wave height. These losses include the property damage or inefficiencies in a port operation which the structure is intended to reduce or prevent. The program optionally provides an estimate of expected annual economic losses due to wave attack, given the parameters of the long-term (extremal) cumulative probability distribution of significant wave heights. The detailed technical basis for application of BWLOSS1 in a breakwater optimization process is presented by Smith (1985).

Program Capabilities: The method of least squares is applied to historical data on economic losses and significant wave height of the storms that caused the losses. A loss function is derived in the following form :

$$\$L(H_s)=\$L_{max}(1-\exp_{-} A(H_s-H_{Lo})\ ) \text{ for } H_s \geq H_{Lo}$$

where

$\$L(H_s)$ = the economic losses associated with the significant wave height H_s;

$\$L_{max}$ = the maximum conceivable economic loss from wave attack;

A = a site specific coefficient derived in the program by the method of least squares;

H_{Lo} = the maximum significant wave height for which losses are negligible (i.e. no losses occur with lesser significant wave heights).

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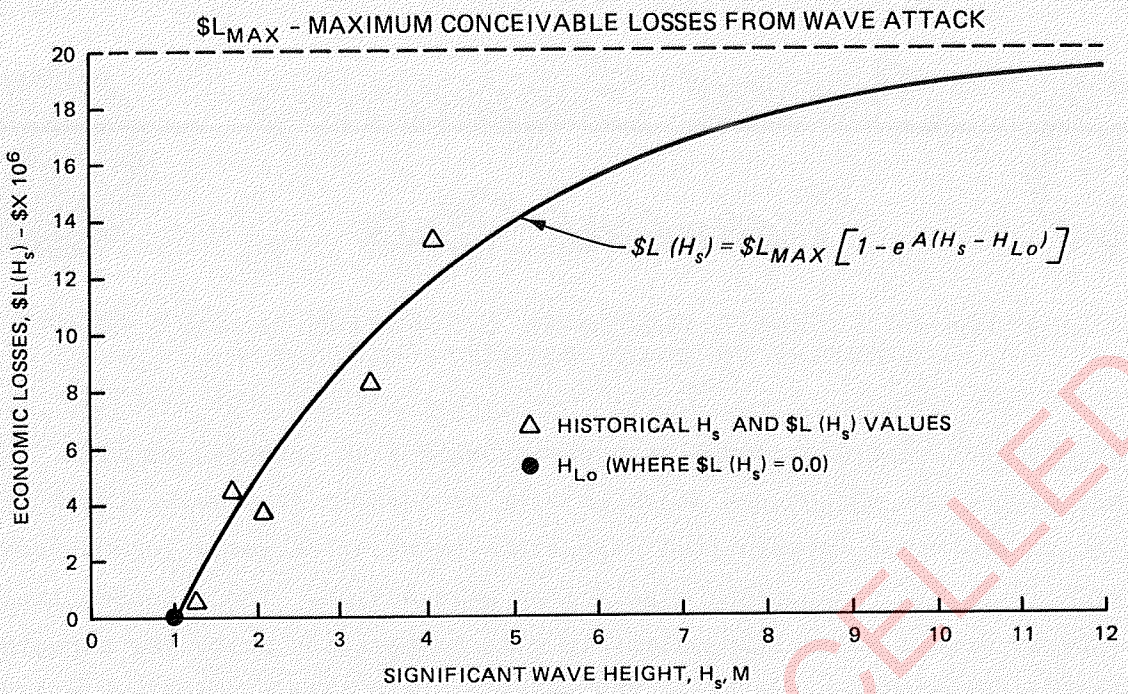

Figure 1. Example plot of economic loss function

The form of this function is illustrated in Figure 1. The program requires at least one historical [H_S, $L(H_S)$] point, but can deal with up to 100. Statistical confidence in the predictions improves with a larger number of historical data points. The coefficient A is presented along with two measures of statistical confidence: the non-linear correlation coefficient and the sum of squared residuals. A table of residuals is optionally printed. The program will predict a specific loss given the significant wave height and/or will predict a significant wave height from a specific loss. The program will also optionally apply a user specified Extremal Type I, Weibull, or Log-Extremal cumulative probability distribution of significant wave heights to predict expected annual losses. These distributions have the following forms:

(1) Extremal Type I $\quad F(h_s) = Pr(H_S<h_s) = \exp(-\exp(-(h_s- \varepsilon)/\Phi))$;

(2) Weibull $\quad F(h_s) = Pr(H_S<h_s) = 1-\exp(-(h_s/B)^{\alpha})$;

(3) Log-Extremal $\quad F(h_s) = Pr(H_S<h_s) = \exp(-(B/h_s)^{\alpha})$.

The parameters for these distributions can be derived from computer program WAVDIST, (CETN-I-40, 1985).With one of these distributions, an expression for the expected annual economic losses, $E\{L(Hs)\}$, can be formulated as follows (DeGroot, 1975):

$$E\{\$L(H_s)\}=\lambda \int_{-\infty}^{\infty} \{\$L(h_s)\ d/dH_s[F(h_s)]\}dH_s$$

where

λ = the average number of extreme events per year (also termed the Poisson lambda parameter).

λ may be derived by application of the MACE program WAVDIST(CETN-I-40,1985) or directly from historical records. This factor is necessary to present the expected losses as an annual average. The program assumes that the number of extreme events occurring per unit time can be accurately modeled by a Poisson random variable which is independent of the random variable H_s. Since wave heights below a height of H_{Lo} cause no damage, the expected annual economic losses may be rewritten as

$$E\{\$L(H_s)\}=\lambda \int_{H_{Lo}}^{\infty} \{\$L(h_s)d/dH_s[F(h_s)]\}dH_s$$

The integration is accomplished in BWLOSS1 by a numerical application of Simpson's Rule with 100 intervals.

The majority of the expected annual losses statistically accumulate for storms whose H_s value is just above H_{Lo}, where the probability density is still substantial. The higher Hs values occur on the upper tail of the probability density function and may even be precluded in prototype by depth limitations. BWLOSS1 does not deal with depth limitations and assumes that the specified $F(h_s)$ fully represents the extremal wave climate at the site.

PROGRAM AVAILABILITY: The program is available in both Microsoft BASIC and FORTRAN for the IBM PC on a 5 1/4-in. diskette or as a printed program listing on the IBM PC or WES Honeywell DPS-8 and may be obtained from Ms. Gloria J. Naylor at (601) 634-2581 (FTS: 542-2581), Engineering Computer Programs Library Section, Technical Information Center, U.S. Army Engineer Waterways Experiment Station, P. O. Box 631, Vicksburg, MS 39180-0631. Questions concerning the applications of BWLOSS1 can be directed to Mr. Doyle L. Jones at (601) 634-2069 (FTS: 542-2069).

INPUT:

1. Maximum conceivable economic loss due to wave attack, $\$L_{max}$
2. Maximum significant wave height for which losses are negligible, H_{Lo}
3. Historical economic losses in current dollars and the responsible significant wave heights
4. Choice of Extremal Distribution, its parameters, and the average number of extremal events per year (optional)

OUTPUT:

1. Economic loss function, $\$L(H_s)$
2. Residual table (optional)
3. Predicted economic loss from a specified significant wave height (optional)
4. Predicted significant wave height corresponding to a specified level of economic loss (optional)
5. Expected annual economic loss due to wave attack, E $\$L(H_s)$/yr (optional)

SAMPLE PROBLEM: The maximum conceivable economic loss at a certain coastal site due to storm waves is twenty million dollars. The maximum significant wave height for which losses are negligible is 2 feet. Significant wave heights of recorded storms in feet and the documented losses they caused in millions of dollars are 4 and 3, 8 and 8, and 10 and 10. What is the predicted economic loss for a significant wave height of 15 feet? What is the significant wave height which would cause a loss of 9.9416 million dollars ? What is the expected annual economic loss at the project site in millions of dollars, given that $F(h_s)$ has Extremal Type I form with $\varepsilon = 6.936$, $\Phi = 1.019$ and a value of $\lambda = 3.9$.

SAMPLE RUN:

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ESTIMATION OF ECONOMIC LOSSES AS A FUNCTION OF WAVE HEIGHT
BWLOSS1
VERSION 5-86
************************************************************
*  BWLOSS1 IS A PROGRAM WHICH FITS AN EXPONENTIAL          *
*  CURVE TO HISTORICAL INFORMATION ON ECONOMIC LOS-        *
*  SES CAUSED BY WAVE ATTACK.  EACH STORM CAUSING          *
*  LOSSES IS ASSUMED TO BE CHARACTERIZED BY A SIN-         *
*  GLE SIGNIFICANT WAVE HEIGHT.  THE PROGRAM RE-           *
*  QUIRES ESTIMATES OF THE MAXIMUM LOSS SUSTAINABLE        *
*  FROM WAVE ATTACK, THE MAXIMUM SIGNIFICANT WAVE          *
*  HEIGHT FOR WHICH LOSSES CAN BE NEGLECTED AND AT         *
*  LEAST TWO HISTORICAL LOSSES WITH ASSOCIATED WAVE        *
*  HEIGHT.  THE EXPONENTIAL CURVE IS COMPUTED BY           *
*  METHOD OF LEAST SQUARES.  ITS PARAMETERS AND            *
*  NON-LINEAR CORRELATION ARE PRINTED.                     *
*    THE PROGRAM WILL ALSO ESTIMATE EXPECTED ANNUAL        *
*  LOSSES GIVEN THE PARAMETERS FOR THE LONG-TERM           *
*  CUMULATIVE PROBABILITY DISTRIBUTION OF SIGNIFICANT      *
*  WAVE HEIGHTS AT THE SITE.  THE PROGRAM WILL AC-         *
*  CEPT THREE DIFFERENT DISTRIBUTIONS: (1) EXTREMAL        *
*  TYPE I; (2) WEIBULL; AND (3) LOG-EXTREMAL               *
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INPUT PROJECT NAME ? SAMPLE SURUN OF BWLOSS1

INPUT THE MAXIMUM CONCEIVABLE LOSS IN MILLIONS OF DOLLARS ? 20

INPUT THE MAXIMUM SIGNIFICANT WAVE HEIGHT FOR WHICH LOSSES ARE
NEGLIGIBLE ? 2

HOW MANY SIGNIFICANT WAVE HEIGHT VS LOSS DATA POINTS DO YOU HAVE ? 3

ENTER SIGNIFICANT WAVE HT., COMMA, LOSS IN MILLIONS OF DOLLARS
AND <return> FOR EACH POINT
? 4,3
? 8,8
? 10,10


        ESTIMATION OF ECONOMIC LOSSES AS FUNCTION OF WAVE HEIGHT

                          SAMPLE RUN OF BWLOSS1

DATA ON EXPONENTIAL CURVE . . .

CURVE HAS FORM: $L(Hs)=$Lmax*(1-exp[A*(HS-HLo)])
$Lmax=      20.000
HLo   =      2.0
A     =     -0.085915
$L(Hs)=     LOSS DUE TO Hs
Hs=         SIGNIFICANT WAVE HEIGHT
NON-LINEAR CORRELATION IS    0.99975
SUM SQR RESIDUALS . . .      0.03136
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SIGNIFICANT WAVE HEIGHT      DOLLAR LOSS
                              MILLIONS
----------------------------------------
         2.0                    0.0
         4.0                    3.0
         8.0                    8.0
        10.0                   10.0
------------------------------------------------------------------------
MAXIMUM CONCEIVABLE LOSS IS 20.0 MILLION DOLLARS
MAXIMUM SIGNIFICANT WAVE HEIGHT FOR WHICH LOSSES ARE NEGLIGIBLE IS  2.0

PRINT RESIDUAL TABLE (Y OR N) ? Y

 XVALUE     YVALUE      YEST        DIFF
 2.0000     0.0000      0.0000      0.0000
 4.0000     3.0000      3.1576      0.1576
 8.0000     8.0000      8.0558      0.0558
10.0000    10.0000      9.9416      0.0584

DO YOU WANT TO MAKE SOME LOSS PREDICTIONS FROM SIGNIFICANT WAVE
HEIGHT DATA (Y OR N) ? Y

INPUT SIGNIFICANT WAVE HEIGHT ? 15

SIGNIFICANT WAVE HEIGHT =  15
PREDICTED LOSS IN MILLIONS OF DOLLARS IS  13.454

DO YOU WISH TO MAKE ANOTHER PREDICTION (Y OR N) ? N

DO YOU WANT TO PREDICT SIGNIFICANT WAVE HEIGHTS FROM LOSS DATA (Y OR N )? Y

INPUT LOSS IN MILLIONS OF DOLLARS ? 9.9416

LOSS (MILLIONS OF DOLLARS)  9.9416
PREDICTED SIGNIFICANT WAVE HEIGHT IS  10.0

DO YOU WISH TO MAKE ANOTHER PREDICTION (Y OR N) ? N

DO YOU WANT TO PREDICT EXPECTED ANNUAL LOSSES (Y OR N) ? Y

SELECT A DISTRIBUTION

EXTREMAL TYPE I...(1)
WEIBULL.....(2)
LOG-EXTREMAL.....(3)

SELECT 1, 2, OR 3 ? 1

INPUT EXTREMAL TYPE I EPSILON AND PHI? 6.936,1.019

INPUT AVERAGE NUMBER OF EXTREMAL EVENTS PER YEAR,THE POISSON 'LAMBDA' PARAMETER? 3.9

EXPECTED ANNUAL LOSS IN MILLIONS OF DOLLARS IS      29.180
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REFERENCES:

Borgman, L. and Resio, D. 1982. "Extremal Statistics in Wave Climatology," Topics in Ocean Physics, Soc. Italina di Fisica, Bologna, Italy.

"Computer Program WAVDIST: Extremal Significant Wave Height Distributions," Coastal Engineering Technical Note (CETN-I-40), U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

DeGroot, M. 1975. Probability and Statistics, Addison-Wesley Publishing Co., Reading, MA.

Smith, O. P. 1985. "Cost effective Optimization of Rubble-mound Breakwater Cross-Sections," CERC Technical Report 86-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.